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(54) Localising system for robotic vehicles

(57) Localising system and method suitable for use with a robotic lawn mower (1), wherein a plurality of spaced reference stations (5 to 7) are associated with an area (L) to be worked by a mobile work station (lawn mower 1) in given positions in relation thereto and wherein the mobile work station (1) communicates with the or two or more of the spaced reference stations (5 to 7) to determine its distance from and bearing with respect thereto, thereby localising the position of the mobile work station (1) relative to the working area (lawn L), such determination being used to enable the mobile work station (1) to carry out a task over at least part of the working area (L) in a controlled manner. The communication may be effected using ultrasonic or electromagnetic radiation. Applications also include robotic floor cleaners etc.

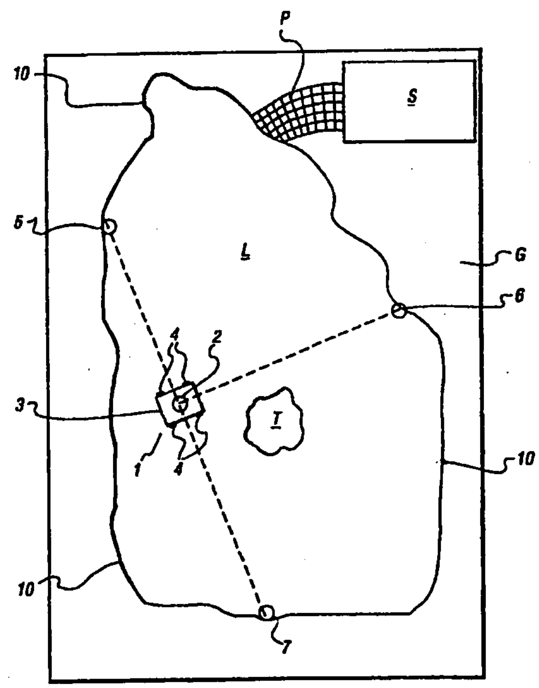

FIG.1

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

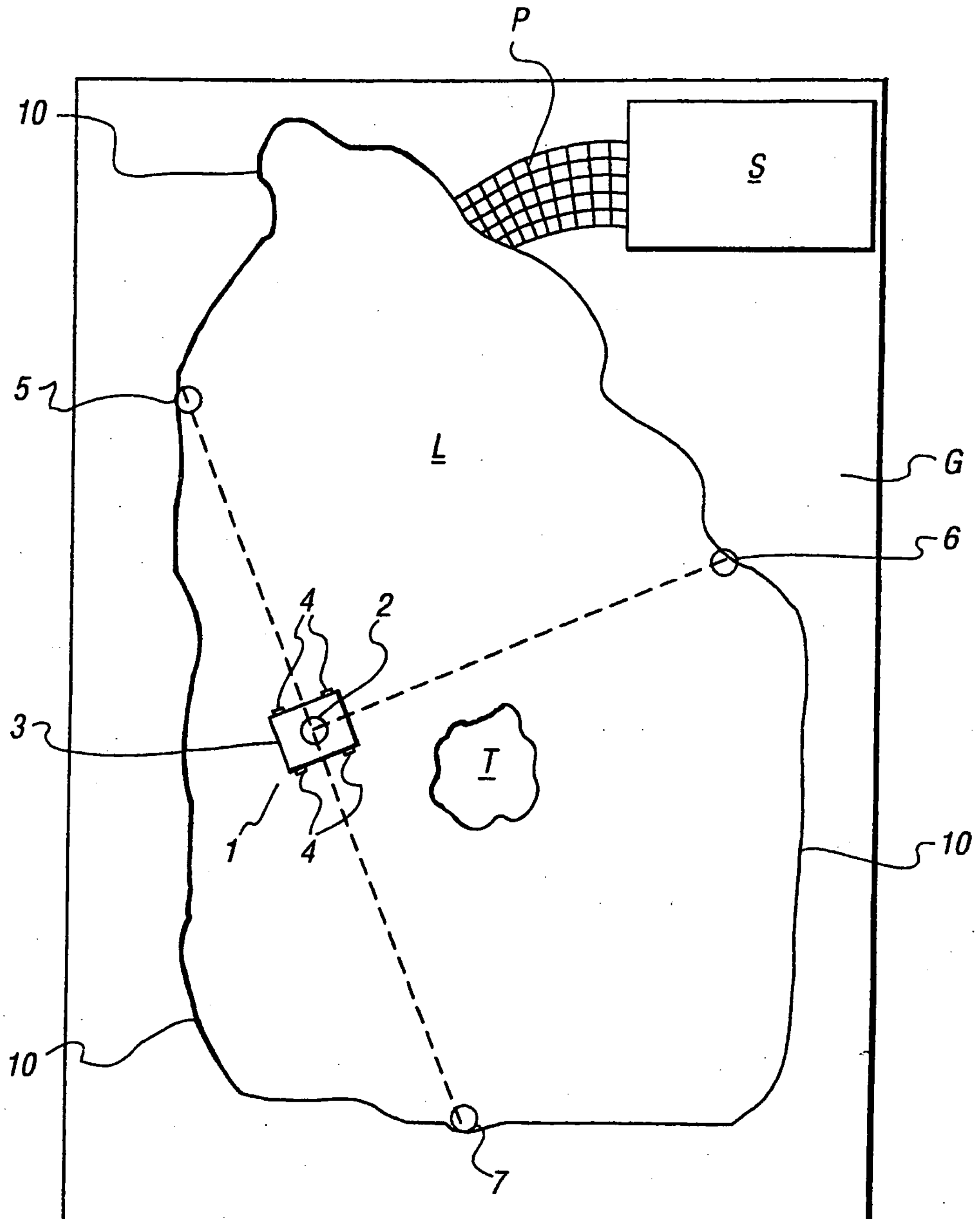

FIG.1

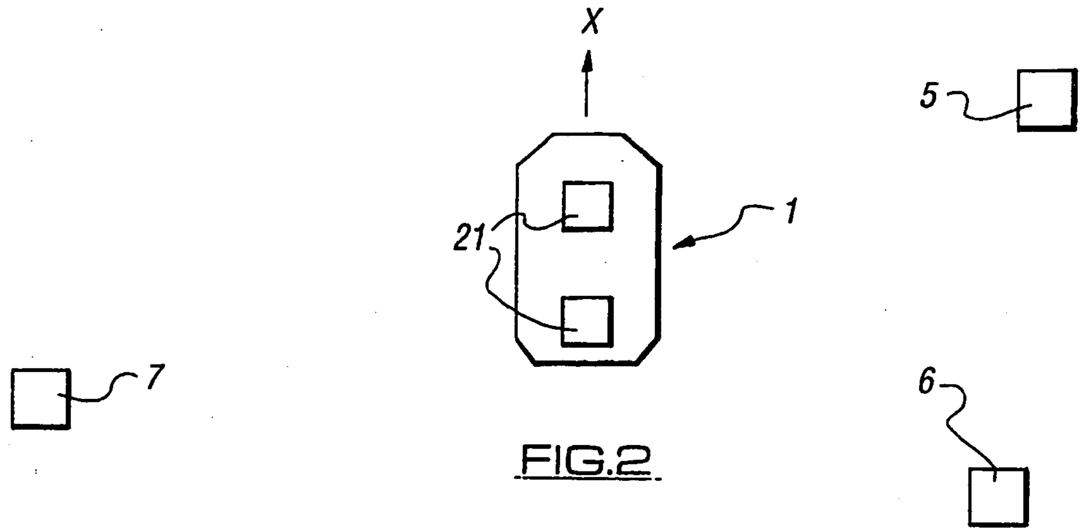

FIG.2

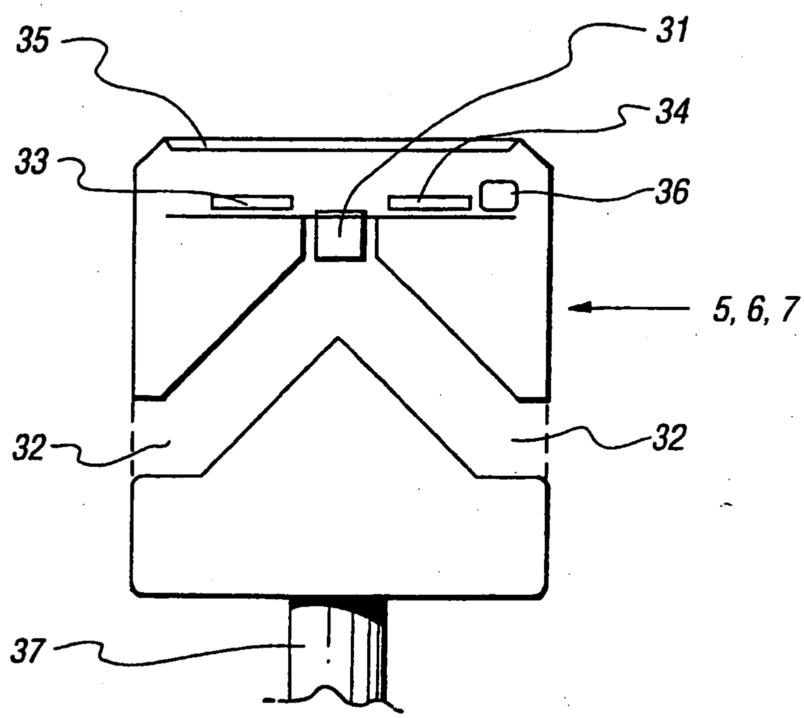

FIG.3

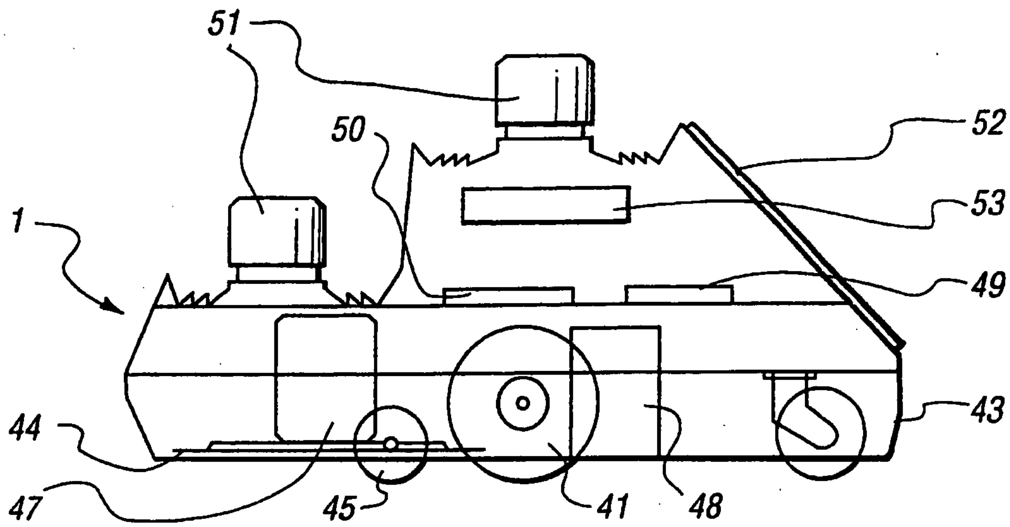

FIG.4A

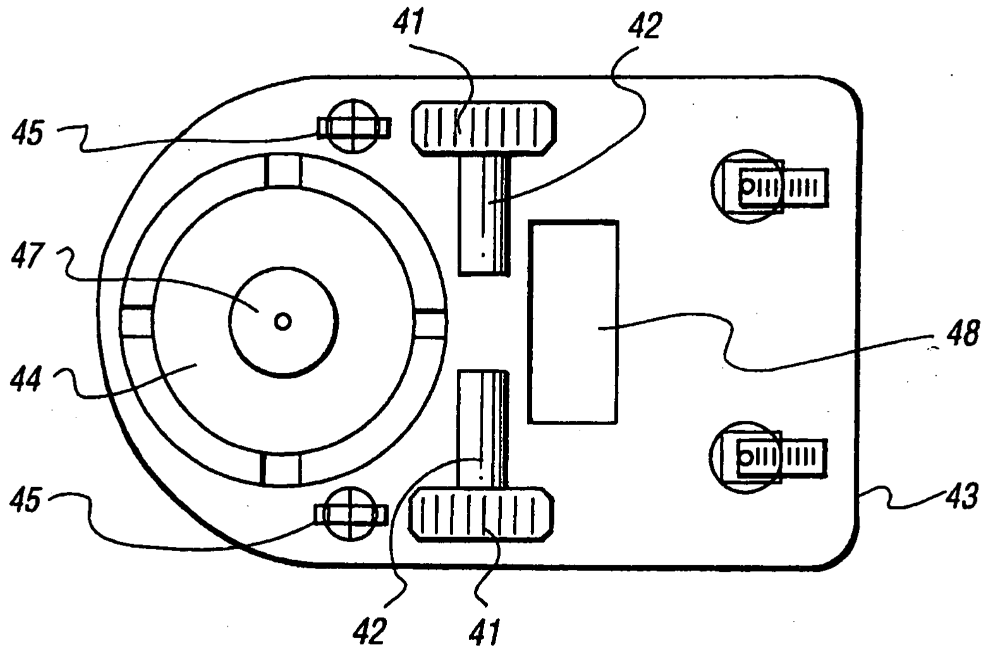

FIG.4B

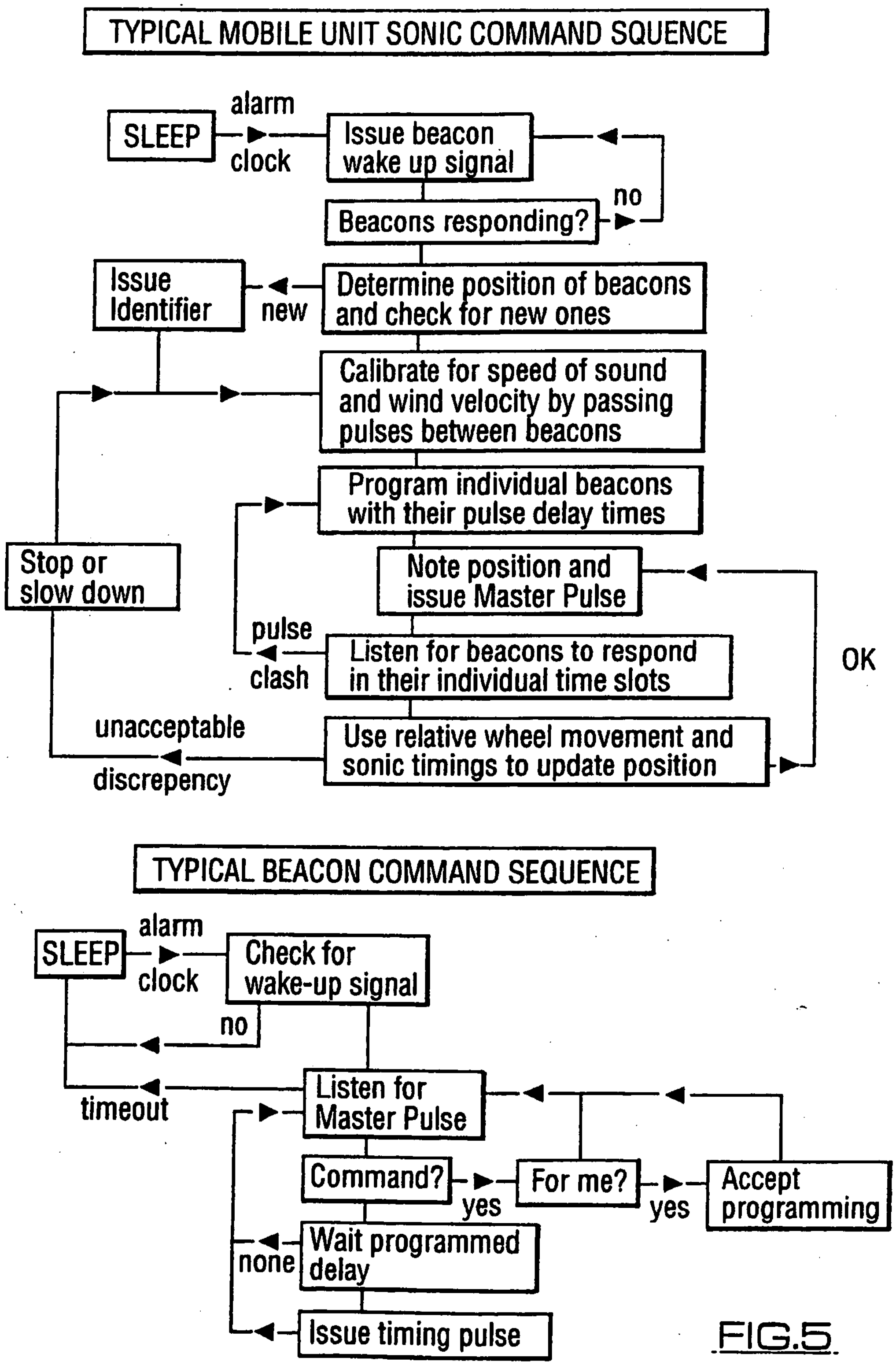
TYPICAL MOBILE UNIT SONIC COMMAND SQUENCE
SLEEP
alarm
clock
Issue beacon wake up signal
Beacons responding?
no
Issue Identifier
new
Determine position of beacons and check for new ones
Calibrate for speed of sound and wind velocity by passing pulses between beacons
Program individual beacons with their pulse delay times
Stop or slow down
Note position and issue Master Pulse
pulse
clash
Listen for beacons to respond in their individual time slots
OK
unacceptable
discrepency
Use relative wheel movement and sonic timings to update position
TYPICAL BEACON COMMAND SEQUENCE
SLEEP
alarm
clock
Check for wake-up signal
no
timeout
Listen for Master Pulse
Command?
yes
For me?
yes
Accept programming
none
Wait programmed delay
Issue timing pulse

FIG.5

LOCALISING SYSTEM

DESCRIPTION

This invention relates to a system for and a method of enabling a mobile work station to localise itself, namely, to determine its distance and bearing, with respect to a plurality of fixed reference stations associated with an area to be worked by the mobile station.

The inventive system and method have numerous applications and are especially, but not exclusively, related to a mobile robotic unit which is required to carry out a task over a working area.

One particular application of the invention is relevant to a robotic lawn mower which needs no operator intervention beyond being shown the boundary of a lawn to be mowed, whereafter the mower is able to mow the lawn automatically at predetermined intervals on demand, whilst optionally dumping mowed grass cuttings at given locations and/or returning to a home base, to recharge or refuel, as necessary. The mower can be rendered sensitive to foreign objects, such as people, in its mowing area, such that it will not overrun such objects. The mower may be programmed to mow the lawn in any desired pattern, for instance, spirally or striped.

Such a robotic lawn mower may also be arranged to perform other tasks, such as, distributing fertiliser, weed killer or the like, sweeping and/or collecting fallen leaves.

Another application of th invention is as a

robotic floor cleaner, such as, a vacuum cleaner, floor polisher or the like, for domestic and/or industrial use.

Throughout this specification, the term "mobile work station" is used to denote such devices, and any other devices which are capable of carrying out a task or tasks over a working area in robotic manner.

Accordingly, one aspect of the present invention provides a localising system comprising a plurality of spaced reference stations associated or associable with a working area in given positions with respect thereto, and a mobile work station arranged to communicate with the or two or more of the spaced reference stations to determine its distance from and bearing with respect thereto, thereby localising the position of the mobile work station relative to the working area, such determinations being used to enable the mobile work station to carry out a task over at least part of the working area in a controlled manner.

Another aspect of the invention resides in a method of localising a mobile work station with respect to an area to be worked thereby, wherein a plurality of spaced reference stations are associated with the area to be worked in given positions in relation thereto and wherein the mobile work station communicates with the or two or more of the spaced reference stations to determine its distance from and bearing with respect thereto, thereby localising the position of the mobile work station relative to the working area, such determinations being used to enable the mobil work station to carry out a task ov r at l ast part of the working area in a controlled manner.

The or at least some of the spaced ref rence stations may be capable of communicating with each other or others of the reference stations, to determine their relative spacings and bearings, which determination may then be transmitted to the mobile work station.

The mobile work station may be arranged to determine its distance from and bearing with respect to the or at least two of the spaced reference stations whilst it is stationary, either before or during its carrying out a task over at least part of the working area. Alternatively or additionally, such determinations may be carried out whilst the mobile work station is moving, preferably, over the working area, again before or during its carrying out a task over at least part thereof.

Communication between the spaced reference stations and/or between the mobile working station and the or at least two of the spaced reference stations may be effected by using ultrasonic radiation, although other forms of radiation, such as, electromagnetic radiation, may be employed. Alternatively or additionally, the reference stations may be linked together, for example, by cabling or wiring, to effect communication therebetween. Similarly, the mobile work station may be so-linked to one or more of the spaced reference stations.

The spaced reference stations maybe "passive", in that they can only reflect radiation transmitted from the mobile work station back thereto, to enable the mobile work station to determine its distance from and bearing with respect to th or two or mor of the refer nce stations, in which cas the refer nce

stations are likely not to be able to communicate with each other.

Alternatively, the spaced reference stations may be "active" in that they can be activated and/or interrogated by the mobile work station to enable them to communicate therewith, so that the mobile work station can determine its distance from and bearing with respect to the or two or more of the reference stations. Alternatively or additionally, the spaced reference stations may be arranged to communicate with the mobile work station by means of a continuous transmission of radiation or pulsed radiation without having to be activated thereby or they may be so-activated and/or interrogated on demand by the mobile station to communicate therewith after a given time interval or on receiving a further transmission activating and/or interrogating therefrom.

This arrangement allows the mobile work station to "orchestrate" all transmissions from the mobile station to the or two or more of the reference stations, between the or two or more of the reference stations and from the or two or more of the reference stations to the mobile station. Thus, in one embodiment only the mobile work station need to be used to determine where the reference stations are located and where it is itself relative to the working area.

The localising system of the preferred embodiment is based upon the use of an intelligent, microprocessor-controlled mobile work station capable of activating and interrogating the spaced reference stations which may also b int lligent and microproc ssor-controll d.

The ultrasonic or other radiation can be encod d to communicate information between the spaced reference and/or mobile work stations by, say, pulse modulation, with the stations measuring transmit/receive times to determine the respective distances between them. The stations may use a stereophonic technique, namely, the time difference between receiving the same pulse at two stations, to determine the bearing of a transmitting reference station and/or the mobile work station.

The accuracy of an ultrasonic localising system is largely independent on the speed of sound in air, which can vary considerably due to temperature and/or humidity, and wind speed, and all distance measurements can be calibrated relative to transmission times between the spaced reference stations and, thus, the wind speed deduced. The reference stations may be arranged to compensate also for isotropic changes in speed of the ultrasonic radiation in air due to temperature changes, as well as being able to take into account constant wind speed.

To avoid any ultrasonic pulse clashes and greatly reduce power drain at the spaced reference stations, the system can be calibrated and controlled by the mobile work station which detects a reference station, determines its position relative to others already encountered, and gives it an identifying code, if necessary. The mobile station can then wander at will, activating or interrogating specific reference stations, usually, the nearest one, to respond, measuring transmit/receive times to determine a radial distance fix, and measuring stereophonically to d t rmin a bearing. Exact positional fixes are

obtained by g om try, nam ly, by obtaining three radial distances from different fixed stations and high positional accuracy can be obtained by trilineation. Thus, it is preferred to determine the bearing of the mobile station with respect to the reference stations stereophonically.

This method of specific interrogation means that a reference station only needs to be "woken up" from a low-power "sleep" state when the mobile station is in the area and only needs to transmit at sufficiently a high energy pulse when specifically asked to do so by the mobile station.

In many applications, it may be desirable that the stations be self-contained battery driven units, perhaps operated by the power generated from a solar cell, and hence low power consumption could be important. A further advantage is that multiple stations do not interfere with each other.

A further advantage of the inventive system and method of localisation is that the mobile work station can listen for any natural reflection of its transmitted ultrasonic radiation and detect the range and direction of an object in its vicinity. This information can be used to enable the mobile station to avoid unknown obstacles or take any other action, for example, stopping until the object is removed.

The mobile station may be arranged to programme and/or interrogate the reference stations and cause them to transmit radiation, such as an ultrasonic pulse, of given duration at predetermined time int rvals. By arranging for th period b tw n adjac nt pulses to be sufficiently large for all

choes to have decayed to a negligible magnitude, the leading edge of a successive pulse can be detected very accurately. By having a predetermined pulse rate, the mobile station can avoid any delay in re-interrogating the reference stations, but retains the ability to synchronise such stations, whilst minimising the possibility of two or more ultrasonic pulses clashing with each other. Similarly, by controlling the duration of ultrasonic pulses, the mobile station is able to maximise the accuracy of its localisation with respect to the closest reference station(s), preferably employing very short pulses, whilst boosting signal to noise ratio from more distant reference stations using longer duration pulses. Programmability of the spaced reference stations permits the mobile station to optimise its pulse strategy as it moves over the working area.

As indicated above, the inventive localising system has particular application in association with a robotic lawn mower arranged to mow a working area, namely, a lawn, with the reference stations preferably being spaced around the boundary of the lawn, although such positioning may be otherwise. For instance, one or more of the reference stations may be positioned on the area of the lawn, with, say, one such station positioned at the centre of the lawn.

In a preferred embodiment, the mower, or other mobile work station, is subjected to a calibration phase in which it interrogates the reference stations to determine its spacing therefrom and bearing with respect thereto, possibly after the reference stations have carried out the same exercise with respect to ach oth r.

This localising information is stor d in the microprocessor control unit of the mower or other mobile station. Subsequently or previously, a so-called "learning phase" may be carried out, whereby the mobile work station is moved by a user around the boundary of the working area, to establish an internal model or map thereof which is also stored in the control unit of the mobile station. This learning phase also takes into account areas within the working area upon which tasks are not required to be carried out by the mobile station.

In the case when the spaced reference stations are effectively "wired" together, the wires can be used for several purposes, for example:

1. to carry or share power between the reference stations;
2. to allow "instant" communication between the reference stations, facilitating ultrasonic pulse timing measurements;
3. to act as a fail-safe boundary for the area the mobile station works, whereby that station is able to detect the presence of an alternating current of specific frequency in the wire(s) and, as a result, will not cross it;
4. as an inductive communication loop, in that any mobile station within the area can detect the strength of the magnetic field created by a wire loop, which can be modulated to carry information.

Also, a specific reference station can be employed as a charging point for the mobile station which can "home in" on to it and conn ct up to r charge its power source, such as a battery, wh n

required. The power source for that charging point might be a large solar panel, although any other suitable source may be used.

Alternatively or additionally, the mobile station may be fitted with a solar panel used to recharge its batteries directly. The station itself detects a low-charge situation and goes into a stationary "basking" mode, where the solar panel is actively maintained in the optimum position relative to the sun by the whole mower rotating as necessary. Typically, a 270mm x 270mm solar panel may be used, giving approximately 1Ah at 12 volts per day during the summer. A lawn mower would have a characteristic basking time of, say, two to three days and a mowing time of up to, say, three hours.

Also, the inventive system and method can be used to determine the orientation of the mobile station in space, as will be described in more detail hereinbelow with reference to a preferred embodiment.

In order that the invention may be more fully understood, a robotic lawn mower embodiment in an inventive location system, will now be described by way of example and with reference to the accompanying drawings in which:

Figure 1 is a plan view of the system in association with a garden lawn to be mowed by the mower;

Figure 2 is a diagrammatic plan view of the mower in association with three spaced reference stations of th system;

Figur 3 is a diagrammatic view of one of the reference stations shown in Figure 2;

Figures 4A and 4B are respective diagrammatic side and bottom plan views of the mower of Figure 2; and

Figure 5 shows respective flowcharts for typical ultrasonic sequences of the mower or other mobile work unit and a reference station.

Referring to Figure 1 of the drawings, in general terms, a robotic lawn mower 1 is of largely the same size and construction as a conventional lawn mower except that it incorporates a microprocessor control unit (not shown) accommodated in a housing 2 on the body 3 of the mower 1, and a steering assembly (also not shown) for at least one pair of its wheels 4 upon which the body 3 is mounted. The mower 1 may be provided with a detachable handle for manual use, whilst the microprocessor control unit controls the manoeuvrability of the mower and the associated grass cutting device (not shown).

Optional sensing wheels (also not shown) and/or other suitable sensors, such as the wheels 4, may be used in the mower 1, to ensure that the latter is moving correctly over the desired distances. Also, a fail-safe electro-mechanical arrangement, such as, microswitches, may be used to ensure that the power to the grass cutting device of the mower 1 is cut-off when the mower is tilted significantly from the horizontal.

In more detail, the locati n system compris s also thr e spac d, r fer nce stations 5, 6 and 7 which

are separate and self-contained with respect to each other and which are spaced around the boundary 10 of a lawn L of a garden G, whilst the mower 1 constitutes a mobile work station. The three reference stations 5 to 7 are located at convenient positions on the lawn boundary 10 and may be mounted on posts, although this is not absolutely necessary. Also, the reference stations 5 to 7 are provided with rechargeable batteries, using solar power for recharging and/or operating. The precise positions of the fixed reference stations 5 to 7 are not critical, provided that they are reasonably spread out and fixed in position once installed.

Initially, the system is subjected to a calibration phase wherein the mower 1 is placed randomly between the three fixed reference stations 5 to 7 on the lawn, as shown in the drawing. Using ultrasonic radiation, the microprocessor unit of the mower 1 activates and interrogates each station 5 to 7, such that the mower can determine its distance from and bearing with respect to each of the reference stations. In this manner, the mower 1 localises itself with respect to the fixed reference stations 5 to 7 and, to a certain extent, with respect to the shape of the lawn L to be mowed.

Optionally, the reference stations 5 to 7 can communicate ultrasonically with each other, to determine their relative spacings and bearings with respect to each other, with the relevant information being transmitted to the mower 1, to assist in determining or confirm determination of its distancings and bearings from the reference stations.

For a single station, such as, th mobile station

in the form of the mower 1, to determin its bearing stereophonically with respect to one or more of the fixed reference stations 5 to 7, it requires two receivers, namely, a pair of ultrasonic transducers 21, as shown in Figure 2. Whilst each fixed reference station 5 to 7 may require only to measure its distance from the other fixed stations and, thus, has only one ultrasonic receiving transducer (monaural), the mower 1 (mobile station) has two such transducers 21 (multiaural). Such a multi-transducer arrangement permits the mower 1 to determine not only its distance from and bearing with respect to each of the fixed stations 5 to 7 but also its body orientation in space. Alternatively, at least one of the reference stations 5 to 7 and/or the mobile work station, in this case, the mower 1, may be provided with a single transducer arranged to transmit and/or receive radiation in an omnidirectional manner using a suitable "horn" arrangement, preferably of cylindrical construction.

With the localising information now stored in the microprocessor control unit of the mower 1, a so-called "learning phase" is carried out, whereby the mower 1 is steered manually around the boundary 10 of the lawn L, commencing with the largest enclosed area, namely, the lawn itself in this particular case. This may or may not be carried out during an initial mowing operation. Internal boundaries, such as island beds or trees T, within the boundary 10 of the lawn L are also included in this learning phase, so that the microprocessor control unit of the mower 1 monitors continuously its position during this phase and, on completion, is able to define for itself a working area within specifi d boundari s.

Using this internal model or map gen rated during the calibration and learning phases, the control unit of the mower 1 is able to steer the latter, such that it mows only the lawn defined by that model or map. The control unit may also be programmed to cause the mower 1 to mow the lawn L in any desired pattern, for instance, spirally or striped.

This learning phase can be extended by the user moving the mower 1 manually over the entirety of the lawn L in a mowing pattern which is monitored by and stored in the mower's control unit, to provide an internal model or map thereof. Subsequently, the mower 1 can then move itself to the start of or an intermediate point on the pattern using the stored information determined by previous communication with the reference stations 5 to 7, for example, in the calibration phase, so that it can then replicate the mowing pattern from the start or intermediate point thereof.

If, say, a fixed reference station 5 to 7 fails, then the mower 1 could use this internal model or map to determine its body orientation and, also, use the stereophonic principle to determine its position with respect to a single fixed reference station 5 to 7 which is still operational.

In Figure 3, there is shown diagrammatically one of the fixed reference stations 5 to 7 which comprises an ultrasonic transducer 31 which is used for both the reception and transmission of ultrasonic radiation from and to and the mower 1 and, optionally, the fixed stations. An omnidirectional resonant cavity or horn 32 allows omnidirection rec ipt and transmission of ultrasonic radiation without significant loss s. A

microproc ssor 33 drives ultrasonic transmission pulses directly off "TTL" and senses "TTL" logic levels on an amplified input signal from the transducer 31 via a tuned analogue amplifier 34. The microprocessor 33 is also able to switch off power to at least the amplifier E, thereby saving power. A solar cell 35 and rechargeable battery 36 enable maintenance-free operation of the station which is supported, in use, upon a fixing post 37.

A constructional form of mower 1 is shown diagrammatically in Figures 4A and 4B and comprises a body 43 and a pair of drive rollers 41 and associated main drive motors 42. A rotary cutting device 44 is provided at the front of the mower 1 adjacent a pair of wheels 45 having wheel movement sensors (not shown). An auxiliary motor 47 for driving the rotary cutting device 44 is provided, along with a rechargeable battery 48, a microprocessor 49, an analogue motor control 50 and a solar panel 52.

Two ultrasonic transducer arrangements 51 each similar to the corresponding arrangement for each fixed station 5 to 7, as described above in relation to Figure 3, receive and transmit ultrasonic radiation from and to the fixed reference stations 5 to 7.

The main drive motors 42 are controllable independently of each other and rotation thereof is sensed, so as to allow the microprocessor 49 to maintain a dynamic model of the movement of the mower 1. Rotation of the front wheels 45 is also monitored to determine distances moved by the mower 1.

During the mowing operation, the moving mower 1 is communicating ultrasonically with the fixed

r ference stations 5 to 7 by actuating and interrogating them to maintain its localising function with respect thereto.

The calibration phase only requires repeating if a fixed station 5 to 7 is moved, whilst the learning phase needs to be repeated if the working area of the lawn L is changed.

A more detailed explanation of the operation of the system will now be given, wherein the mower 1 transmits ultrasonic radiation to preprogramme each fixed reference station 5 to 7 to transmit subsequently a single pulse after waiting for both an ultrasonic pulse from the mower and the expiration of a predetermined time interval which is different for each fixed station.

As the mower 1 moves over the lawn L, it transmits a master pulse and also "listens" stereophonically for any reflected pulses, thereby detecting the presence and position of any obstacle in its path of movement.

Although the fixed reference stations 5 to 7 are interrogated by the mower 1, they are "silent" for long enough for all ultrasonic echoes to decay to insignificant levels.

The preprogrammed timing of the fixed reference stations 5 to 7 then causes one of them to transmit a pulse which is detected and processed by the mower 1. Then, the other reference stations take their turn to transmit successive ultrasonic pulses to the mower 1, so that the latter is able to determine an accurat distance and b aring with r spect to those stations.

The mower 1 then retransmits th master puls and the cycle is repeated, thereby localising the position of the mower with respect to the fixed reference stations 5 to 7 and, hence, the lawn L.

As described above, the orientation in space of the body 3, 43 of the mower 1 is determined stereophonically using the pair of ultrasonic transducer arrangements.

The master pulse transmitted by the mower 1 can be encoded with instructions to adjust the waiting times of the respective reference stations 5 to 7, to establish an optimum pulse cycle repeat rate as the mower moves across the lawn L.

Although the mower 1 moves during these operations, it can use its internal dynamic model to compensate any errors in the localising system. Any such errors can be detected and used to stop the mower 1 so that it can then obtain a corrected "fix" with respect to the reference stations 5 to 7. Typically, two such errors are required before the mower 1 stops and obtains a corrected "fix" with request to the reference stations 5 to 7.

Absolute fixes may also be made conveniently at the end of each "run" of the mower when mowing in striped patterns.

Thus, the mower 1 does not necessarily have to stop to obtain a corrected "fix". Generally it understands its wheel movements to be correct during each ultrasonic cycle and can solve for its latest absolute position whilst moving. Th main reason for this proc ss to fail would be slippage f a wheel 4

during a sonic cycle. Such failure is detected by comparing the predicted distances from the internal dynamics model established by the mower's control unit with those determined during movement of the mower 1 across the lawn L. As indicated above, two such corrective failures are required before the mower 1 stops and obtains a corrected stationary "fix".

The mower 1 may be stored in, say, a shed S, when not in use, and then brought out on to the lawn L via a path P, when required to mow the lawn.

In a more sophisticated but totally automatic arrangement, the control unit of the mower 1 can be programmed to operate the latter at periodic time intervals, with due regard to the weather, to mow the working area of the lawn L, return to the shed S (home base) after the mowing operation and then recharge its power source.

In such a complex arrangement, more than three fixed reference stations 5 to 7 may be required, particularly if two or more lawns L require mowing and are connected by paths along which the mower 1 will have to pass. However, the same calibration and learning phases as those discussed above are still employed, even for a complex arrangement of lawns and connecting paths.

The mower's control unit may be programmed during the learning phase, to differentiate paths from lawn working areas, to that its grass cutting device is not operational whilst the mower 1 is on a path.

Further, an optional dump mode allows the mower's control unit to be programmed to recognis the

location of a dump where grass cuttings can be dumped. Such a location, as well as those of any connecting path(s) and the configuration thereof, is included in the model or map generated during the learning phase, as discussed above.

Specific instructions may be given to the mower's control unit by an operator using either a control panel on the mower or a hand-held, remote programmer or personal computer, instructing the mower to, say, mow or not mow particular portions of the working area of the lawn L or to mow to a particular pattern.

Although the mower 1 and fixed reference stations 5 to 7 can communicate with each other ultrasonically, the accuracy of the system is substantially independent of the speed of the ultrasonic radiation in air, which can vary considerably due to temperature, humidity and/or wind direction changes, because all the distance measurements carried out by the mobile station (mower 1) and the fixed reference stations 5 to 7 can be calibrated relative to transmission of the ultrasonic radiation between the fixed stations.

Further, the mower 1 is also able to detect ultrasonically any foreign body in its path on the lawn L, whereby it can be stopped quickly. Additionally or alternatively, a mechanical fail-safe arrangement, such as, microswitches, may be employed.

Although the embodiment of inventive localising system described above in relation to the drawing uses ultrasonic radiation for communication between the mower 1 and/or the fix d r ferenc stations 5 to 7, other forms of radiation, such as, electr magnetic

radiation, may be employed.

A possible modification of the ultrasonic arrangement described above would be to add electromagnetic radiation to allow a faster fix at an absolute position. For example, the mobile station emits an ultrasonic pulse whilst at a position A, possibly whilst in motion. Each fixed reference station receive the pulse, waits a period of time specific to itself to avoid clashes and then emits an electromagnetic pulse. The mobile station receives the electromagnetic pulse and, as the transmission time is negligible compared with the ultrasonic pulses, can determine the time taken for the pulse emitted at position A to reach each fixed station. From this, position A can be determined by trilineation.

A passive light beam arrangement for the fixed reference stations 5 to 7 could be used analogous to the intelligent ultrasonic arrangement discussed above, in that the station positions are "learnt" by the mobile station but where the fixed stations are merely light beam reflectors, namely, reflective cams or tri-cornered reflectors designed to return a beam in the reverse direction irrespective of its incidence angle, such a beam may be in the invisible infra-red range. The mobile station senses the angular direction of such "passive" stations and, optionally, the time-of-flight of a light pulse in order to determine a range.

In a simple implementation, an infra-red light-emitting diode and a matching photoelectric sensor diode are mounted pointing vertically at a rotating prism or mirror rotating at a comparatively slow rat

of, say, 1-10Hz and its angular position sensed to th required accuracy.

For a typical mower wherein the required positional accuracy is of the order of 1cm at a distance of 10m from a fixed reference station, the prism angle needs to be sensed to 1/20th of a degree (3 minutes), that is to say, 10,000 angular positions per revolution would be adequate. At each graticule position, the background light level is measured at the sensor diode, a pulse of light is emitted and a timer started. By monitoring the sensor diode output during the maximum expected two-way flight time of the pulse, namely, the next 70ns for a 10m range, the return pulse will be detected against the background, should the fixed station be at this angular position. The time of flight of the pulse gives an approximate range for the reflection and this, plus the knowledge of the expected approximate angular position, will aid positive identification of a true fixed station reflection. Accurate positional information is calculated using triangulation off several stations.

In an arrangement involving no moving parts, the light pulse is directed horizontally in all directions by a conical mirror and the returning light directed down by the same mirror on to an annulus of charge-coupled sensitive elements, similar to those used in cameras. In a simple methodology, the annular array of elements is exposed and the background intensities noted. The annular array is then cleared and the light pulse emitted. After waiting the maximum time-of-flight, the contents of the array are again noted. The first set of calibration data is then subtracted, giving th r turn intensiti s du to the light puls . Fixed stations ar identified by int nsity level and

approximat annular position and an accurate fixed obtained, again, by triangulation.

An active light beam arrangement for the fixed stations similar to the passive arrangement can be employed although the mobile station simply senses the light pulses and has no transmission capability. The light pulses are emitted periodically by active fixed reference stations equipped with light-emitting diodes and, perhaps, powered by solar energy. Each station has a different periodicity, enabling it to be easily identified from background light sources. In this case an exact position is calculated by triangulation once again.

The same "learnt" reference arrangement can be implemented using active radio frequency fixed stations transmitting at different known frequencies. By sensing the phase difference of the incident wave on a pair of aerials, the mobile station is able to deduce the angular position of a particular fixed station and by using three or more such stations, the mobile station is able to calculate an exact position by trilineation.

Figure 5 shows respective flowcharts for typical command sequences of the control unit of the mower 1 or other mobile work station and a reference station 5 to 7, wherein the mower is referred to as the "mobile unit" and the reference station as a "beacon".

CLAIMS

1. A localising system comprising a plurality of spaced reference stations associated or associable with a working area in given positions which respect thereto, and a mobile work station arranged to communicate with the or two or more of the spaced reference stations to determine its distance and bearing with respect thereto, thereby localising the position of the mobile work station relative to the working area, such determination being used to enable the mobile work station to carry out a task over at least part of the working area in a controlled manner.

2. A system according to claim 1, wherein the or at least some of the spaced reference stations are capable of communicating with each other or others of the reference stations, to determined their relative spacings and bearings.

3. A system according to claim 2, wherein determination of the relative spacings and bearings of the spaced reference stations is communicable to the mobile work station.

4. A system according to any preceding claim, wherein the mobile work station is arranged to determine its distance from and bearing with respect to the or at least two of the spaced reference stations whilst it is stationary.

5. A system according to claim 4, wherein such determination whilst the mobile work station is stationary, is arranged to be carried out before or during its carrying out a task over at least part of th working ar a.

6. A system according to any preceding claim, wherein the mobile work station is arranged to determine its distance from and bearing with respect to the or at least two of the spaced reference stations whilst it is moving over the working area.

7. A system according to claim 6, wherein such determination whilst the mobile work station is moving over the working area, is arranged to be carried out before or during its carrying out a task over at least part of the working area.

8. A system according to any preceding claim, wherein one or more of the spaced reference stations is passive.

9. A system according to any preceding claim, wherein one or more of the spaced reference stations is active.

10. A system according to claim 9, wherein the or each active reference station can be activated by the mobile work station.

11. A system according to claim 10, wherein the or each active reference station can be interrogated by the mobile work station after it has been activated thereby.

12. A system according to any preceding claim, wherein one or more the spaced reference stations is arranged to communicate with the mobile work station by means of a continuous transmission.

13. A system according to any preceding claim, wherein on or more of the spac d reference stations

is arranged to communicat with the mobile work station by means of pulsed transmissions.

14. A system according to any preceding claim, wherein one or more of the spaced reference stations can be activated and/or interrogated by the mobile work station to communicate therewith after a given time interval or on receiving a further activating and/or interrogating transmission therefrom.

15. A system according to any preceding claim, wherein the mobile work station is intelligently microprocessor-controlled.

16. A system according to any preceding claim, wherein at least one of the spaced reference stations is intelligently microprocessor-controlled.

17. A system according to any preceding claim, wherein communication between the mobile work station and one or more of the spaced reference stations and/or between two or more of the reference stations is arranged to be effected using ultrasonic or electromagnetic radiation.

18. A system according to any preceding claim, wherein two or more of the spaced reference stations are linked together by cabling or wiring, to effect communication therebetween.

19. A system according to any preceding claim, wherein the mobile work station is linked to at least one of the spaced reference stations by cabling or wiring, to effect communication therebetween.

20. A system acc rding to any pr ceding claim,

wherein ultrasonic or other radiation can b ncoded to communicate information between spaced reference stations and the mobile work station.

21. A system according to claim 20, wherein the encoded information is pulse modulated.

22. A system according to any preceding claim, wherein the spaced reference and/or mobile work stations are arranged to measure transmit/receive times therebetween to determine respective distances between them.

23. A system according to any preceding claim, wherein a stereophonic technique is employed to determine the bearing of a communicating reference station and/or the mobile work station.

24. A system according to any preceding claim, wherein the spaced reference stations can be calibrated to compensate for ambient temperature, pressure and wind speed changes.

25. A system according to any preceding claim, wherein the mobile work station is arranged to detect a reference station, determine its position relative to other, already-detected reference stations and provide said detected reference station with an identifying code.

26. A system according to any preceding claim, wherein the mobile work station is capable of detecting the range and direction of an object in the vicinity thereof.

27. A system according to any preceding claim,

wh rein the mobil work station is arranged to programme and/or interrogat the spaced reference stations and cause them to transmit radiation thereto at predetermined time intervals and of given duration.

28. A system according to any preceding claim, wherein the spaced reference stations are positioned or positionable around the boundary of an area to be worked by the mobile station.

29. A system according to any preceding claim, wherein the mobile work station is arranged to be subjected to a calibration phase, to determine its distance from and bearing with respect to two or more of the spaced reference stations.

30. A system according to any preceding claim, wherein the mobile work station is arranged to carry out a learning phase, whereby it is moved around the boundary of the working area, to establish and store an internal model or map thereof.

31. A system according to any preceding claim, wherein the mobile work station is arranged to be moved manually over substantially the entirety of the working area in a mowing pattern, to monitor such pattern and to store such pattern in an associated control unit, to provide an internal model or map thereof, for subsequent controlled movement of the mobile work station over the working area in a pattern which is a replica of the stored mowing pattern.

32. A system according to any preceding claim, wherein a reference station can be used as a charging point for th mobil work station.

33. A system according to claim 32, wh rein said reference station includes a solar panel as a power source.

34. A system according to any preceding claim, wherein the mobile work station includes a solar panel for recharging purposes.

35. A system according to claim 34, wherein the solar panel of the mobile work station can be actively maintained in the optimum position relative to the sun.

36. A system according to any preceding claim, wherein at least one of the spaced reference stations is provided with a single transducer arranged to transmit and/or receive radiation in an omnidirectional manner.

37. A system according to any preceding claim, wherein the mobile work station is provided with a single transducer arranged to transmit and/or receive radiation in an omnidirectional manner.

38. A system according to claim 36 or 37, wherein the transducer is arranged to transmit and/or receive radiation in an omnidirectional manner by means of a horn arrangement.

39. A system according to claim 38, wherein the horn arrangement is of a generally cylindrical construction.

40. A system according to any preceding claim, wher in the mobile work station is arranged to carry out, in a controlled manner, another task on or remote

from the working area.

41. A system according to any preceding claim, wherein the or at least two of the spaced reference stations are arranged to communicate with each other and/or the mobile work station using light beams.

42. A system according to claim 41, wherein the light beams are in the form of pulses.

43. A system according to claim 41 or 42, wherein the light beams are in the invisible infra-red.

44. A system according to any preceding claim, wherein the mobile work station is in the form of a lawn mower.

45. A system according to any of claims 1 to 43, wherein the mobile work station is in the form of a floor cleaner, polisher or the like.

46. A robotic lawn mower system according to any preceding claim, when operated in accordance with the command sequence flowcharts shown in Figure 5 of the accompanying drawings.

47. A method of localising a mobile work station with respect to an area to be worked thereby, wherein a plurality of spaced reference stations are associated with the area to be worked in given positions in relation thereto and wherein the mobile work station communicates with the or two or more of the spaced reference stations to determine its distance from and bearing with respect thereto, thereby localising the position of the mobil work stati n r lativ to th working ar a, such d t rminations being used to enable

the mobile work station to carry out a task over at least part of the working area in a controlled manner.

48. A method according to claim 47, wherein the or at least some of the spaced reference stations communicate with each other or others of the reference stations, to determined their relative spacings and bearings.

49. A method according to claim 47 or 48, wherein determination of the relative spacings and bearings of the spaced reference stations is communicated to the mobile work station.

50. A method according to claim 47, 48 or 49, wherein the mobile work station determines its distance from and bearing with respect to the or at least two of the spaced reference stations whilst it is stationary.

51. A method according to claim 50, wherein said stationary determination is carried out before or during the mobile work unit's carrying out a task over at least part of the working area.

52. A method according to any of claims 47 to 51, wherein the mobile work station determines its distance from and bearing with respect to the or at least two of the spaced reference stations whilst it is moving over the working area.

53. A method according to claim 52, wherein said mobile determination is carried out before or during the mobile work unit's carrying out a task over at least part of the working ar a.

54. A method according to any of claims 47 to 53,

wherein one or more of the spaced reference stations is passive.

55. A method according to any of claims 47 to 54, wherein one or more of the spaced reference stations is active.

56. A method according to claim 55, wherein the or each active reference station is activated by the mobile work station.

57. A method according to claim 56, wherein the or each active reference station is interrogated by the mobile work station after it has been activated thereby.

58. A method according to any of claims 47 to 57, wherein one or more the spaced reference stations communicates with the mobile work station by means of a continuous transmission.

59. A method according to any of claims 47 to 58, wherein one or more of the spaced reference stations communicates with the mobile work station by means of pulsed transmissions.

60. A method according to any of claims 47 to 59, wherein one or more of the spaced reference stations is activated and/or interrogated by the mobile work station to communicate therewith after a given time interval or on receiving a further activating and/or interrogating transmission therefrom.

61. A method according to any of claims 47 to 60, wherein th mobile work stati n is int llig ntly microprocessor-controlled.

62. A m thod according to any of claims 47 to 61, wherein communication between the mobile work station and one or more of the spaced reference stations and/or between two or more of the reference stations is effected using ultrasonic or electromagnetic radiation.

63. A method according to any of claims 47 to 62, wherein two or more of the spaced reference stations are linked together by cabling or wiring, to effect communication therebetween.

64. A method according to any of claims 47 to 63, wherein the mobile work station is linked to at least one of the spaced reference stations by cabling or wiring, to effect communication therebetween.

65. A method according to any of claims 47 to 64, wherein ultrasonic or other radiation is encoded to communicate information between spaced reference stations and the mobile work station.

66. A method according to claim 65, wherein the encoded information is pulse modulated.

67. A method according to any of claims 47 to 66, wherein the spaced reference and/or mobile work stations measure transmit/receive times therebetween to determine respective distances between them.

68. A method according to any of claims 47 to 67, wherein a stereophonic technique is employed to determine the bearing of a communicating reference station and/or the mobile work station.

69. A method according to any of claims 47 to 68,

wh rein the spac d refer nc stations are calibrated to compensate for ambient temperature, pressure and wind speed changes.

70. A method according to any of claims 47 to 69, wherein the mobile work station detects a reference station, determines its position relative to other, already-detected reference stations and provides said detected reference station with an identifying code.

71. A method according to any of claims 47 to 70, wherein the mobile work station detects the range and direction of an object in the vicinity thereof.

72. A method according to any of claims 47 to 71, wherein the mobile work station programmes and/or interrogates the spaced reference stations and causes them to transmit radiation thereto at predetermined time intervals and of given duration.

73. A method according to any of claims 47 to 72, wherein the spaced reference stations are positioned around the boundary of an area to be worked by the mobile station.

74. A method according to any of claims 47 to 73, wherein the mobile work station is subjected to a calibration phase, to determine its distance from and bearing with respect to two or more of the spaced reference stations.

75. A method according to any of claims 47 to 74, wherein the mobile work station carries out a learning phase, whereby it is moved around the boundary of the working area, to stablish and stor an internal mod l or map th r of.

76. A method according to any of claims 47 to 75, wherein the mobile work station is moved manually over substantially the entirety of the working area in a mowing pattern, to monitor such pattern and to store such pattern in an associated control unit, to provide an internal model or map thereof, for subsequent controlled movement of the mobile work station over the working area in a pattern which is a replica of the stored mowing pattern.

77. A method according to any of claims 47 to 76, wherein a reference station is used as a charging point for the mobile work station.

78. A method according to claim 77, wherein said reference station includes a solar panel as a power source.

79. A method according to any of claims 47 to 78, wherein the mobile work station includes a solar panel for recharging purposes.

80. A method according to claim 79, wherein the solar panel of the mobile work station is actively maintained in the optimum position relative to the sun.

81. A method according to any of claims 47 to 80, wherein at least one of the spaced reference stations is provided with a single transducer arranged to transmit and/or receive radiation in an omnidirectional manner.

82. A method according to any of claims 47 to 81, wh r in the mobile work station is provided with a single transducer arranged to transmit and/or r ceive

radiation in an omnidirectional manner.

83. A method according to claim 81 or 82, wherein the transducer transmits and/or receives radiation in an omnidirectional manner by means of a horn arrangement.

84. A method according to claim 83, wherein the horn arrangement is of generally cylindrical construction.

85. A method according to any of claims 47 to 84, wherein the mobile work station carries out, in a controlled manner, another task on or remote from the working area.

86. A method according to any of claims 47 to 85, wherein the or at least two of the spaced reference stations communicate with each other and/or the mobile work station using light beams.

87. A method according to claim 86, wherein the light beams are in the form of pulses.

88. A method according to claim 86 or 87, wherein the light beams are in the invisible infra-red.

89. A method according to any of claims 47 to 88, wherein the mobile work station is provided in the form of a lawn mower.

90. A method according to any of claims 47 to 88, wherein the mobile work station is provided in the form of a floor cleaner, polisher or the like.

91. A localising method substantially as hereinbefore described.

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Databases (see below)
(i) UK Patent Office collections of GB, EP, WO and US patent specifications.

(ii) ONLINE WPI

Documents considered relevant following a search in respect of Claims :-
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Category	Identity of document and relevant passages		Relevant to claim(s)
X	GB 2264184 A	(STATE OF ISRAEL) see eg page 6, lines 1-19	1, 47 at least
X	GB 1582415	(ENERGYSTICS) see eg page 1, lines 30-45	1, 47 at least
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